

RECENT OBSERVATIONS OF THE FORMATION OF FILAMENTS

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Abstract

Two examples of the formation of small filaments in $H\alpha$ are described and illustrated. In both cases, the formation is seen to be the spontaneous appearance of strands of absorbing mass that evolve from no previous structure. The initial development of the filaments appears to consist of the accumulation of these absorptive strands along approximately parallel paths in a channel between large-scale, opposite polarity magnetic fields on either side of the filaments. The strands exhibit continuous changes in shape and degree of absorption which can be due to successive condensations resulting in new strands, mass motions within the strands, and outflow of the mass from the strands. For at least several hours before the formation of both filaments, small-scale fragments of opposite polarity, line-of-sight magnetic flux adjacent to or immediately below the filaments, and at the ends of the filaments, were cancelling. This type of magnetic flux disappearance continued during the development of the filaments and is commonly observed in association with established filaments. Cancellation is interpreted as an important evolutionary change in the magnetic field that can lead to configurations suitable for the formation of filaments.

INTRODUCTION

A few examples of the formation of filaments taking place over intervals of one to several days can be found in Smith (1968) and in the review by Martin (1973). Two examples of new filaments forming on time scales of minutes are illustrated and discussed in this paper. These examples were found in time-lapse series of $H\alpha$ filtergrams recorded at the Big Bear Solar Observatory during the past two years. Videomagnetograms of the line-of-sight component of photospheric magnetic fields were continuously acquired at the time of formation of these filaments.

DESCRIPTION OF INDIVIDUAL EXAMPLES

5 August 1984 Filament Formation

The minute by minute evolution of a small active region in $H\alpha$ images and videomagnetograms was recorded for about 10 hours per day from 31 July until 8 August 1985. The formation of a new filament was observed on 5 August during the decaying phase of the region. Additional growth of the filament occurred during the night hours of the Big Bear Solar Observatory. The day to day evolution of this active region and the details of the decay of

its magnetic flux are is discussed and illustrated in Martin et al. (1985). In this paper, we present only the details of the formation of the new filament.

Images before, during, and after the formation phase are shown in Figure 1. This filament forms completely in the 14 minute interval between 2208 and 2222. At 2216:46, the developing filament appears to consist of 3 absorptive strands aligned end to end. After formation, the filament lengthens and shortens while increasing and decreasing in absorption but remains a distinct feature until the end of the observing day (0127, 6 Aug.). The formation of the filament in $H\alpha$ consists of the spontaneous appearance of roughly parallel, short strands of absorbing mass. The strands do not originate from any pre-existing structure but they are approximately aligned with the underlying chromospheric fibrils. The strands of absorption continuously change shape and lengthen or disappear in periods of a few minutes. The formation appears as a sporadic but gradually increasing accumulation of these linear absorptive strands until they constitute a completely-formed filament.

By the following day, the newly formed filament is part of a much longer filament that occupies nearly the entire length of the polarity inversion zone of the decaying active region (Fig. 12, Martin et al. 1985).

The development of the new filament relative to the surrounding line-of-sight component of the magnetic flux of the active region can be seen in videomagnetograms in the right side of Figure 1. All of the magnetic fragments correspond to concentrations of plage in $H\alpha$. In these magnetograms from the Big Bear Solar Observatory, negative fields are black and positive fields are white except within the contours of the stronger fragments of flux. Each successive inner contour where the color reverses from white to black or black to white, represents an increase in the field strength by about a factor of 2. The lowest contours in Figures 1 correspond to field strengths of approximately 50 Gauss. The weakest fields in these magnetograms are on the order of 10 Gauss.

Comparison of the magnetograms and $H\alpha$ images in Figure 1 shows that the new filament is bounded by fragments of mostly negative flux on the left and mostly positive flux on the right. To the left side of the filament is a small fragment of positive flux adjacent to the larger fragments of negative flux. The positive fragment is cancelling with the negative fragments at a rate of 10^{19} Maxwells per hour (cancelling feature PN25 in Martin et al. (1985)). Within 10 minutes after the formation of the new filament, this cancellation ceases because all of the positive fragment has disappeared. An obvious result of this cancellation is the shifting of the center of the polarity inversion zone to the right of its former site. It is unlikely that the filament could have formed any earlier at its precise location because it would have been surrounded by substantial positive flux rather than being between opposite polarity fields.

Cancellation sites also exist close to the upper end of the newly formed filament (P26, P27/N27 in Fig. 6, Martin et al. 1985). The magnetograms on the next observing day show that there was substantial loss of magnetic flux along the division between opposite polarities since the preceding day. Because the filament develops further during this stage of rapid loss of flux, we question whether the the cancellation of flux and the growth of filament are physically related, indirectly related, or whether they are simply coincident but unrelated phenomenon. Zwaan (1978) anticipated these observations of disappearing magnetic flux near the sites of filaments and suggested that the maintenance of filaments might be related to the disappearance of magnetic flux by means of magnetic reconnection.

5 AUG 1984

30,000 Km

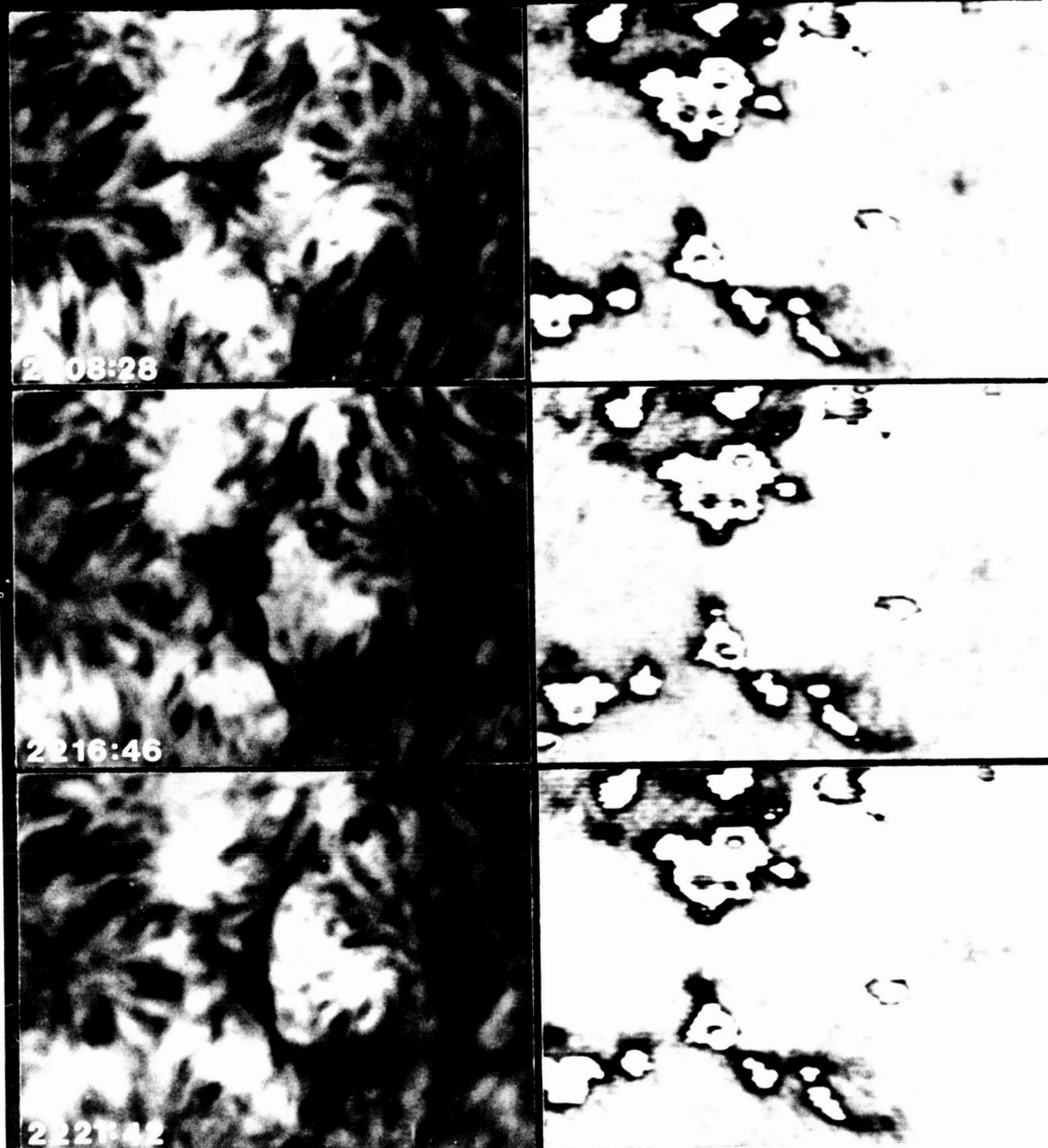


Fig. 1. The initial stages of the formation of a filament within a decaying active region are seen in $H\alpha$ images at the left. The formation consists of the spontaneous appearance of short strands of absorptive mass. The magnetograms show that the formation is coincident with the final few minutes of the cancellation of a positive (white) fragment of flux with the negative flux (black) to the left of the site of formation. Slower cancellation of fragments of flux at the upper end of the filament also occurs before and during the development of the filament. The polarity of individual clumps of magnetic flux containing contours are the same as around the periphery of the contoured areas.

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OF POOR QUALITY

On this date, the formation of a small quiescent filament was observed on the quiet sun. A series of $H\alpha$ images depicting typical changes before, during and after its formation are shown in Figure 2. The formation of this quiescent filament takes place more slowly than the formation of the filament in the decaying active region. Otherwise, the formation is similar to the example above. Intermittent strands developed and faded from the beginning of the observing day at 1500 UT until 1710 UT. At 1710 the conspicuous strand, visible in the frame image at 1722 in Figure 2, formed. From that time until the end of the day, the filament was a continuously enduring structure. The filament occupies the same path as the earlier short-lived pre-formation strands. The strands are approximately parallel to the chromospheric fibrils assumed to be below the strands. From the beginning of the day, the chromospheric fibrils were already in the sheared configuration (Hagyard et al. 1984). The filament develops about midway between the adjacent opposite polarity fields and appears to divide rather than join the dominant large scale fields on opposite sides of the filament channel.

The series of images in Fig. 2 reveals how the structure within the filament is continuously changing during and after its formation. As in the other example, there is no evidence that the filament mass originates from any pre-existing chromospheric structure. Although we cannot discern exactly how the formation takes place, these observations are consistent with the well-known prominence observations at the limb which show prominence mass appearing to condense out of the corona. In this example strands of absorptive material spontaneously develop against the background of the chromosphere. They become darker and longer in periods of a few minutes to tens of minutes and then fade from view. Some of the strands are irregular in shape and hence may be composed of smaller unresolved strands.

Prior to the time that the absorptive strands become a completely developed filament (1722 in Fig. 2) earlier strands are seen to appear and disappear sporadically. The disappearance could be due to reheating of the strands. However, their changing shape and disappearance would also be consistent with the flow of mass from the corona to the chromosphere as is also often observed in time-lapse prominence films over the limb.

After the filament has formed, it continues to reveal continuous absorptive changes in the darkness of its resolvable internal structure and in its overall width and length. Again, this dynamic behavior would be consistent with the continuous process of condensation of mass from the corona and its subsequent flow into the chromosphere.

The magnetic flux around the newly formed filament is shown in the last frame in Figure 2. In the magnetogram there is a uniformly gray vertical streak that intersects a similar gray horizontal streak. These are artifacts where no magnetic field was recorded. In spite of this deficiency, the magnetograms do clearly show that opposite polarity fields exist on either side of the site where the filament formed. Additionally, the time-lapse sequence of magnetograms shows that cancellation of small fragments of flux occurs under the filament and near the upper end during and after its formation.

MAGNETIC FLUX CHANGES ASSOCIATED WITH FILAMENTS

We have recorded the line-of-sight magnetic fields under and adjacent to filaments on several occasions during the last year. Representative images from the time-lapse films taken

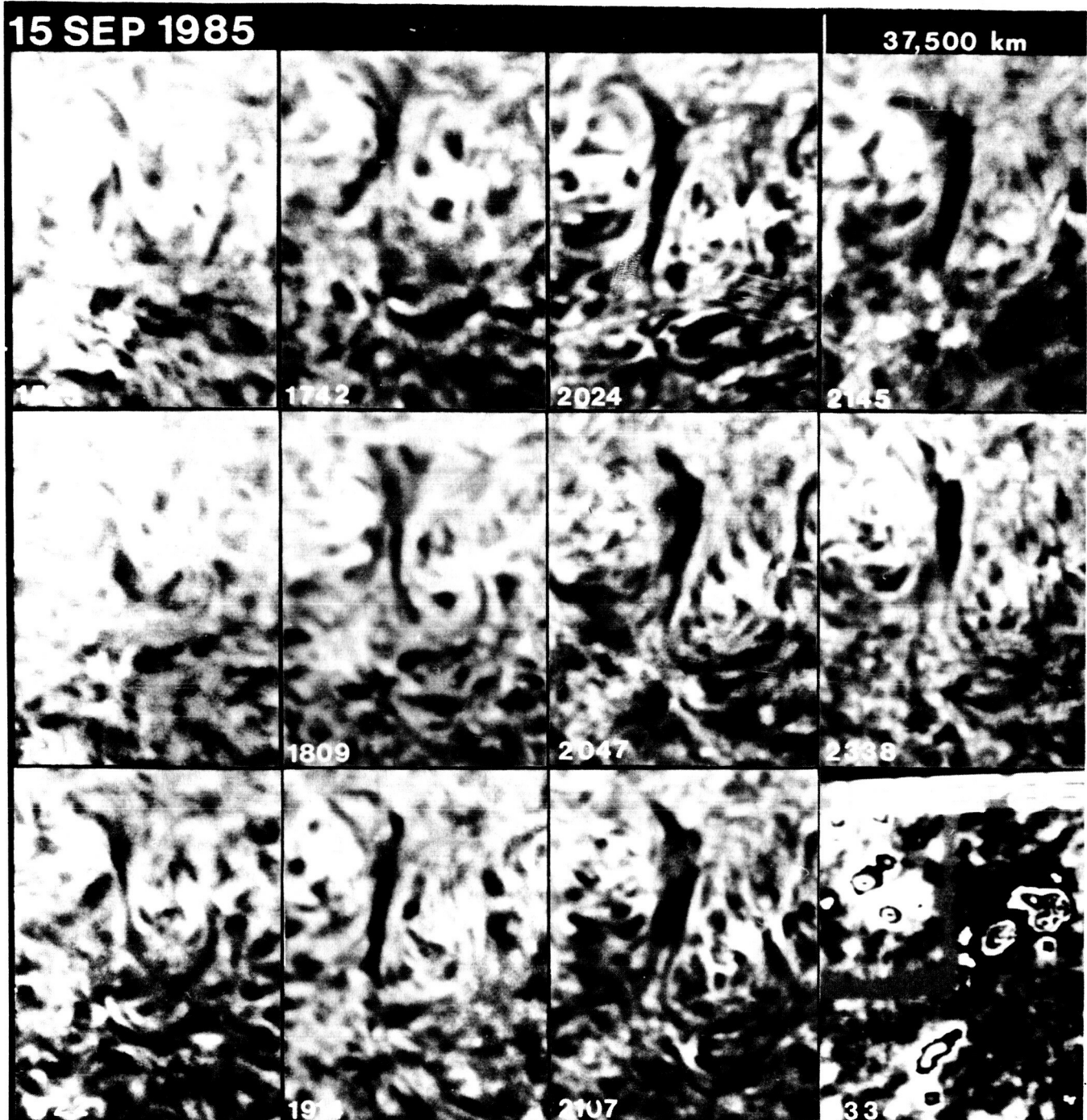


Fig. 2. The formation of this filament on the quiet sun takes at least 2 hours. After 1710, it is a continuously visible structure. Prior to this time, absorptive strands appear and disappear along the path where the filament will form. The continuous changes in the shape of the filament after its formation can be interpreted as the continued formation and disappearance of additional strands that appear to be merged in our line of sight. The magnetogram in the last frame shows that the filament is forming between line-of-sight magnetic flux of opposite polarity.

on 29 and 30 August 1985 are shown in Figure 3. The time-lapse magnetograms show that fragments of opposite polarity magnetic flux frequently move into juxtaposition and become small sites of cancelling magnetic flux. Filaments usually become very narrow where they cross cancelling fragments of magnetic flux. In other cases, such as at the left end of the filament in Figure 3, the end of the filament or a segment of the filament appears to terminate at the site of the cancelling fields rather than threading its way between the opposite polarity fragments. These circumstances suggest the possibility of a direct magnetic linkage between the sites of disappearing line-of-sight magnetic flux and the maintenance or growth of the predominantly horizontal field of filaments, an association already made in a general way by Zwaan (1978).

Very small-scale filaments illustrated and discussed by Hermans and Martin (1986, this volume) often have one end that terminates at the polarity division of small-scale cancelling features, similar to the two examples of newly formed filaments described herein. On the other end of size spectrum, large-scale filaments such as in Figure 3 appear to be just longer versions of the small filaments such as the one in Figure 2. All of these filaments, ranging from very small to large, are associated with sites of cancelling flux.

Cancellation is not unique to filament channels but it is the primary magnetic change that takes place under filaments or at the ends of filaments or the ends of filament segments. Cancellation can take place between any closely spaced magnetic flux fragments of opposite polarity (Martin 1984; Livi et al. 1985; Martin et al. 1985). Under filaments, such as in Figure 3, the cancellation of opposite polarity network is common, but the emergence of new flux under the filament may also create new sites of cancellation wherever the new flux is adjacent to opposite polarity network.

A test of the significance of the coincidence of cancellation to the formation or maintenance of filaments, could be made by observing filament channels with and without filaments. If the coincidence is physically significant, one would expect to find that filament channels without filaments would also have a deficiency of cancelling fragments relative to the number of cancelling fragments in filament channels occupied by a filament. Conversely, one would expect filaments to preferentially form or form earlier in zones where opposite polarity magnetic fields are converging such as between adjacent spreading active centers. Tang (1986) has recently shown that quiescent filaments on the quiet sun occur more often at polarity boundaries between active centers than within active centers.

DISCUSSION

The formation of the filaments illustrated in this paper does not occur by the migration of opposite polarity fields in opposite directions along the polarity inversion zone. Neither do they evolve from fibrils or field transition arches which one could imagine to gradually turn from connecting opposite polarities to dividing opposite polarities. The filament is a new structure. It divides or separates opposite polarities. Within the resolution of our images, even the ends of filaments appear to terminate closer to the division between opposite polarities rather than to the concentrations of magnetic flux on either side of the polarity division. This is a difficult distinction to make with the data because the magnetograms have lower spatial resolution than the $H\alpha$ filtergrams. The magnetograms consist of video frames integrated over many seconds to minutes while exposure for the $H\alpha$ filtergrams is a fraction of a second. Due

to image motion during the greater exposure time required for the magnetograms, the spatial resolution of the videomagnetograms is degraded relative to the $H\alpha$ images. Magnetograms having higher spatial resolution are needed to more precisely define the association of $H\alpha$ features with the small elements of magnetic flux.

Because there is insufficient mass in the corona around filaments to account for their mass (references in review by Forbes 1986), one looks to an alternative supply of mass from the chromosphere. However, during the formation of these filaments, the $H\alpha$ time-lapse images give no direct evidence of the transport of mass from the chromosphere into a filament. The

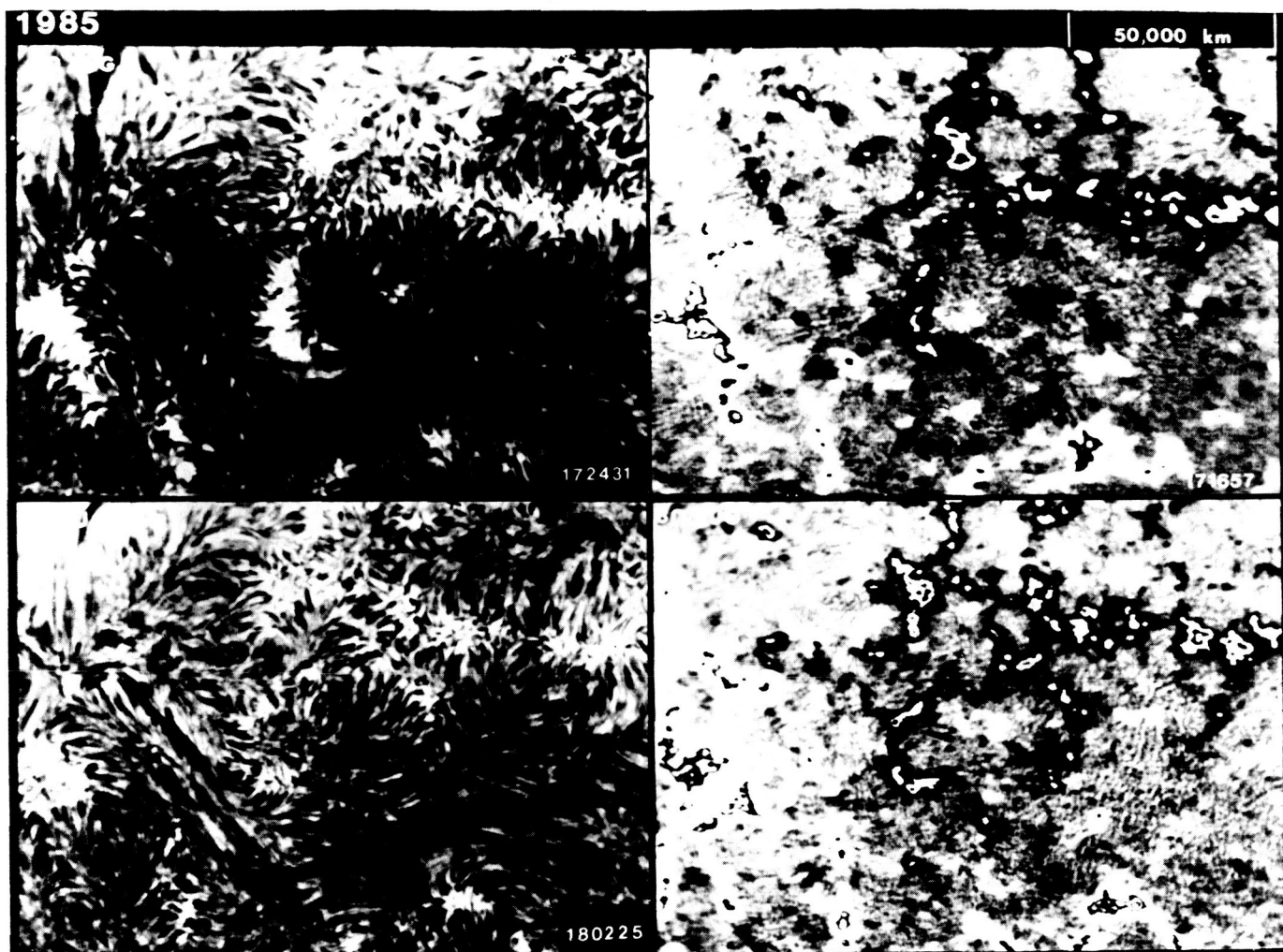


Fig. 3. Comparison of the structure of a filament in $H\alpha$ (left) with the line-of-sight magnetic flux under and adjacent to the filament (right). At the left end of the filament opposite polarity fragments of magnetic flux move together and cancel. Sporadic cancellation of similar small fragments of magnetic flux typically occurs under filaments such as this one. Note that the filament becomes very narrow or breaks into segments where opposite polarity fragments are close together. Negative flux is black and positive flux is white except within the contours. These are areas of stronger magnetic field where each successive inner contour represents an increase in the field by a factor of 2 but the polarity is the same as around the periphery of the contours.

H α observations seem only to confirm previous coronal observations in which the filament mass appears to condense out of the corona. A new clue to the mass supply for filaments is suggested from our observations of cancelling magnetic flux at the ends of filaments or filament segments. The relative orientation of filaments to the cancellation sites is suggestive of a possible link between the field lines of the filament and the magnetic fields of the cancelling features. Because the true magnetic field geometries of both are yet unknown, this linkage is purely hypothetical and no specific magnetic field geometry is proposed in this paper.

It is important to establish more definitively whether the formation of filaments and the cancellation of magnetic flux are: (1) unrelated, (2) indirectly related, or (3) directly related. If directly related, we need to learn whether cancellation is a necessary condition for the formation of filaments.

From the observations described herein, I suggest that cancellation sites might relate to the formation and structure of filaments in the following ways:

- (1) As an evolutionary precondition
- (2) As an environmental influence on the width and path of a filament where it crosses a cancellation site
- (3) As specific locations where ionized mass from the chromosphere could conceivably enter the path of filaments and subsequently condense to form the strands of a filament.
- (4) As locations where the line-of-sight magnetic flux may be changing to horizontal components within filaments because of magnetic reconnection (Zwaan 1978).

Acknowledgments

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